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Environmental Compliance: Requirements and Technology Opportunities for Future Ships

ABSTRACT Navy ships must be able to operate anywhere in the world and visit any port unencumbered by environmental restrictions. The Office of the Chief of Naval Operations (OCNO) has formulated a vision for the environmentally sound ship of the 21st century, which will ensure compliance with environmental requirements applicable to Navy ships, while maintaining fleet effectiveness and readiness.

Navy ships generate a variety of solid and liquid wastes and atmospheric emissions. Ships have limited capabilities for holding wastes for offload to shore. Working closely with the OCNO, the Naval Sea Systems Command (NavSea) is developing systems, equipment, and procedures to process and manage ship wastes in an environmentally responsible manner. Several pieces of shipboard equipment have been successfully developed to process solid and liquid waste, hazardous materials and ozone-depleting substances (ODSs).

The technologies and practices being developed under this program will:
- ensure compliance with environmental laws and regulations,
- significantly reduce the logistic burdens and costs associated with shoreside offload and disposal of ship wastes,
- implement Navy environmental and occupational safety and health policies,
- enhance the quality of life aboard ship, and
- continue the Navy's leadership role in protecting the marine environment.

Introduction

Navy ships must be able to operate anywhere in the world and visit any port unencumbered by environmental restrictions. To maintain the operational effectiveness and readiness of the fleet, the Navy must ensure that its ships can comply with environmental laws and regulations in an economical and mission-compatible manner. The Navy faces several significant challenges as it tries to ensure environmentally responsible fleet operations:
- Navy ships must comply with a wide range of federal, state, and local laws and international and foreign requirements,
- the environmental laws and requirements continue to grow in scope and complexity,
- the international community is gradually applying a coordinated global approach to marine environmental protection,
- there is a trend toward tighter restrictions in coastal areas at the same time restrictions are being expanded to the open ocean, and
- the long ship design and procurement cycle, combined with the multi-decade service lives of Navy vessels, makes it difficult to forecast environmental requirements and to develop appropriate responses.

As ships are being required to control more wastes in more areas around the world, it becomes more important for ship designers to consider pollution prevention and pollution control as important facets of mission performance and readiness, thereby minimizing adverse effects on the ship and crew and avoiding costly pollution control backfits during a ship's service life. The Navy's traditional backfit-for-compliance approach to fleet environmental problems must give way to a more strategic and forward-looking plan for future ships. In addition to environmental compliance, there are significant operational and cost benefits to be gained from ship designs that will be environmentally compliant throughout their service lives and from ship operations that will not have to rely on shoreside support for waste management. These considerations and strategies are embodied in the Office of the Chief of Naval Operations (OCNO) vision for the environmentally sound ship of the 21st century.

This paper describes Navy shipboard wastes, the environmental requirements affecting Navy ships, and the Naval Sea System Command's (NavSea's) ongoing and planned Advanced Development RDT&E projects that present environmental technology opportunities for new surface combatant designs.

Legislative Overview

Many environmental laws, regulations, international agreements, and policy instructions affect Navy shipboard systems and operations. Major U.S. and international environmental laws with requirements applicable to Navy ships are shown in Table 1. In addition, some state and local governments have been targeting Navy ship wastes for regulatory control, adding another complex dimension to fleet environmental compliance. (The specific requirements arising from these laws, regulations, and international agreements will be discussed later for each waste stream.) Although Navy ships are not legally subject to the environmental laws of foreign countries, they are expected to abide by the environmental provisions in the applicable port visit clearance and/or Status of Forces Agreement (SOFA), or otherwise to attempt to abide by the corresponding U.S. requirements or the practices of host-nation warships. Chapter 19 of the Navy's Environmental and Natural Resources Program Manual (OpNavInst 5090.1B) implements applicable federal, state, and

TABLE 1

Major Environmental Laws Affecting the Design and Operation of Navy Ships

Solid Wastes *(plastics, paper, cardboard, metal, glass, textiles, other)*
Clean Water Act
International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), Annex V
Act to Prevent Pollution from Ships
Marine Plastic Pollution Research & Control Act
Section 1003 of National Defense Authorization Act for FY94, Section 1003
Section 324 of National Defense Authorization Act for FY97, Section 324
Ozone-Depleting Substances *(CFC refrigerants, CFC solvents, Halon firefighting agents)*
Montreal Protocol on Substances That Deplete the Ozone Layer (and subsequent amendments)
Clean Air Act Amendments of 1990
Executive Order 12843 (Federal procurement requirements)
Liquid Wastes *(bilge water, ballast water, waste oil, sewage, graywater, other)*
Clean Water Act
International Convention for the Prevention of Pollution from Ships, Annex I & proposed Annex IV
Act to Prevent Pollution from Ships
Oil Pollution Act
National Defense Authorization Act for FY96, Section 325 (Uniform National Discharge Standards)
Hazardous Materials
Clean Water Act
Resource Conservation & Recovery Act
Toxic Substances Control Act
General
National Environmental Policy Act
Marine Mammal Protection Act
Endangered Species Act
National Marine Sanctuaries Act
Executive Order 12856 (pollution prevention)
Executive Order 12114 (environmental effects abroad)
State & local regulations
Foreign-country requirements

local laws for ships and provides additional DoD and Navy guidance for ship environmental compliance.

Environmental laws and regulations applicable to Navy ships have been changing to reflect growing government and public concern about protection of the marine environment. Pollution control must become an integral and important part of the design of new platforms to ensure that warships are not impeded by environmental restrictions around the world and that sailors are not adversely affected by waste handling and retention.

Environmentally Sound Ship of the 21st Century

In recent years, DoD ships and other vessels have come under the type of environmental scrutiny previously applied to land-based facilities. For example, the Act to Prevent Pollution from Ships applies to the Navy and defines a ship as "a vessel of any type whatsoever, including hydrofoils, air-cushion vehicles, submersibles, floating craft whether self-propelled or not, and fixed or floating platforms." Regulatory authorities, environmental groups, and the general public have clearly indicated that discharges from Navy ships in port, in littoral waters, and even in the open ocean will not necessarily enjoy special exemptions simply because of the unique military mission and design constraints of Navy vessels.

The OCNO, through its Environmental Protection, Safety and Occupational Health Division (N45), has a vision for environmentally sound ships of the 21st century, whereby new-design ships must be able to operate in U.S., international, and foreign waters without degradation of mission or quality-of-life attributable to environmental laws and regulations. This means that (1) ships must be designed and operated to minimize waste generation and optimize waste management and (2) shipboard systems must be used to destroy or appropriately treat wastes generated onboard. Figure 1 illustrates the major shipboard waste processing strategies encompassed in this vision. Commanding officers of Navy ships operating in the 21st century must be able to carry out any mission and visit any port worldwide without concern about waste discharge or offload problems arising from national or local requirements. Furthermore, Navy ships must minimize or eliminate their reliance on capital- and labor-intensive shoreside waste disposal facilities which are not available throughout the world. Since it takes many years to design and build Navy ships and the ships will be in service for decades, implementing this vision requires anticipating new environmental requirements that may develop during this long time period and developing appropriate shipboard technologies. This vision for environmentally sound warships for the 21st century has been endorsed by the North Atlantic Treaty Organization (NATO) navies participating in the Special Working Group 12 (SWG/12) on Maritime Environmental Protection within the NATO Naval Armaments Group (NNAG).

Other Program Drivers

Fiscal realities within DoD and the Navy increasingly require monetary justification for environmentally-related expenditures. Return-on-investment analysis is now being applied to shipboard environmental research, development, test, and evaluation (RDT&E) programs, although quantification of environmental costs and benefits is often problematic. NavSea is currently determining the budgetary benefits of shipboard pollution control systems. The good news is that substantial cost savings can be associated with shipboard environmental systems. Eliminating or significantly reducing the fleet's dependence on shoreside waste reception and disposal facilities can avoid substantial infrastructure and operational costs. Good-faith efforts to comply with existing environmental laws and regulations within the constraints of ship design and operation can occasionally avoid the imposition of stricter and more costly pollution control requirements. Shipboard pollution control has an important role to play in maintaining fleet mission and readiness capabilities, reducing operational costs, and enhancing the quality of life at sea.

Program Goal

The Navy's goal for its Shipboard Waste Management RDT&E Project, which is managed by the Ship Research, Development and Standards Group within NavSea, is to develop shipboard equipment, systems, and procedures to:

- manage ship wastes in compliance with existing and emerging environmental restrictions worldwide without jeopardizing ship mission, survivability, or habitability, and
- minimize the cost of fleet environmental compliance.

This effort is driven by existing compliance requirements, the OCNO vision for the environmentally sound ship of the 21st century, and the Navy's interest in protecting the environment.

Shipboard Wastes

The major waste sources to be discussed in this paper are:

- solid wastes (paper, cardboard, food, metal, glass, and plastics),
- ozone-depleting substances (chlorofluorocarbon refrigerants and solvents and Halon firefighting agents),
- oily wastes (bilgewater and compensated fuel system ballast water),
- sewage (human wastes),
- graywater (drainage from showers, sinks, laundry, scullery, etc.),

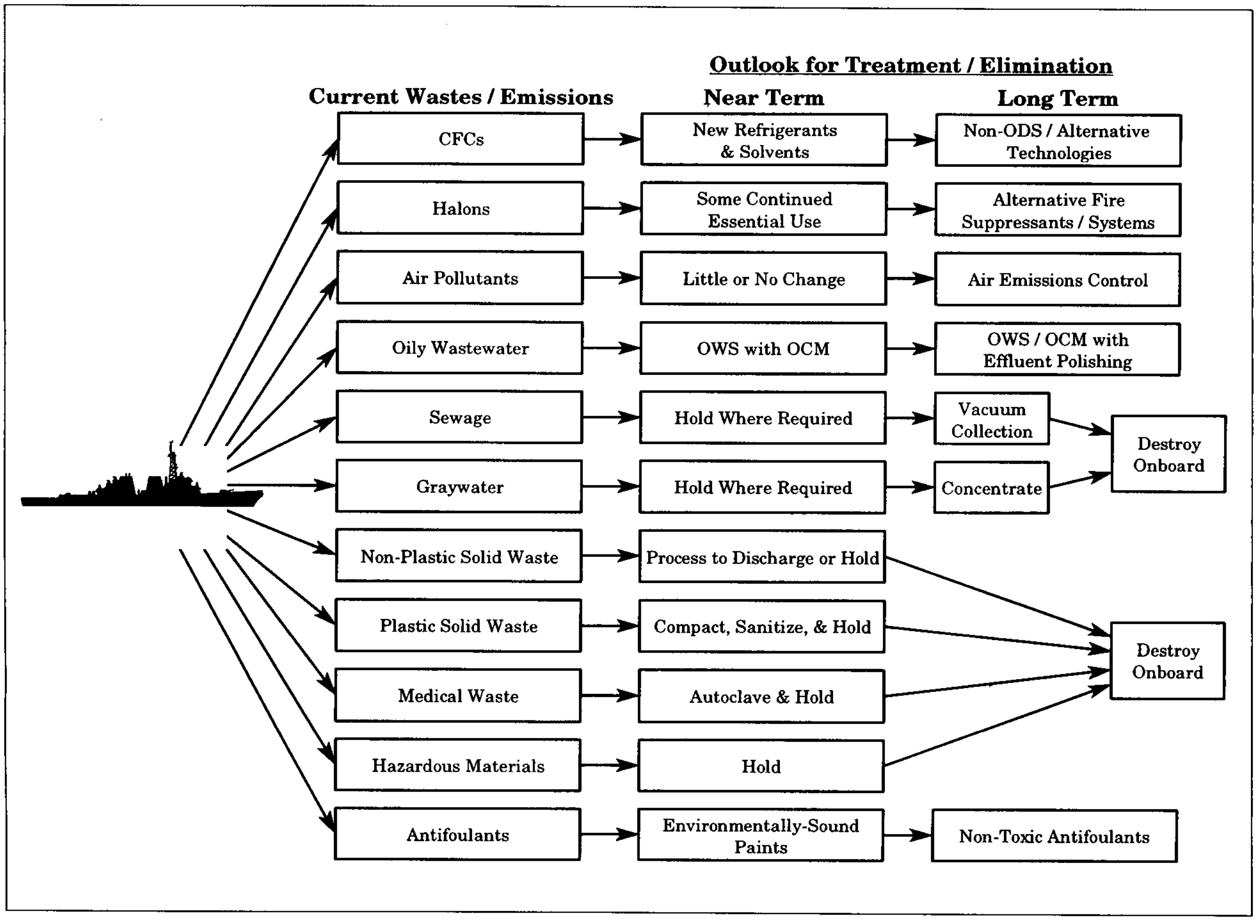

FIGURE 1. Shipboard Environmental Technology Strategy for Environmentally Sound Ship of 21st Century

- hazardous materials (solvents, adhesives, sealants, lubricants, etc.),
- non-hull paints and coatings, and
- asbestos.

The following sections describe the sources, requirements, current shipboard practices, and RDT&E strategy for each of these waste streams.

SOLID WASTES

Sources and Characteristics

Navy ships generate solid wastes similar to trash from households and other land-based facilities such as:

- paper packaging and office waste,
- cardboard packaging,
- metal food and drink containers and some metal scrap from shipboard industrial activities,
- glass bottles for food and drinks,
- food residues,
- rags, clothing, and other textiles, and
- wooden vegetable crates, cable spools, and other items.

A sailor generates over 3 pounds/day (equivalent to 0.43 ft^3/day) of solid waste aboard ship. For a frigate or destroyer with a crew of 300, this amounts to over 82,600 pounds (over 11,600 ft^3) during a 3-month deployment. An aircraft carrier with a complement of 6,000 would accumulate over 3,304,000 pounds (over 464,000 ft^3) of trash during a 6-month deployment. Much of this trash is combustible and much of it is unsanitary because it contains food residues.

Environmental Requirements

U.S. law has imposed the following restrictions on plastic solid waste generated on surface ships:

- No discharge within 25 nm of land.
- When underway, retain the last three days of food-contaminated plastic and the last twenty days of other plastic for return to port.
- No discharge anywhere after 31 December 1998.

In addition, the Navy was specifically required by law to develop and install shipboard plastics processors to meet the December 1998 discharge ban. The following restrictions apply to non-plastic solid waste on surface ships:

- No discharge within 3 nm of land.
- No discharge within 3-25 nm of land unless pulped or comminuted.
- In "special areas" designated by the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), discharge only non-floating garbage as of 31 December 2000, which must be in the form of a slurry of seawater, paper, cardboard, and food beyond 3 nm or shredded and bagged metal and glass beyond 12 nm.

Certain bodies of water have been designated under MARPOL 73/78 as "special areas," where additional pollution control measures have been instituted because of oceanographic and ecological conditions and vessel traffic. Several of these areas (shown in Figure 2), especially the Mediterranean Sea and Caribbean area, are extremely important operational areas for the Navy.

Congress required the Navy to submit by November 1996 a plan for compliance by Navy ships with MARPOL 73/78 Annex V on solid waste as implemented in U.S. law. The preparation of the report to Congress and a supporting environmental impact statement (EIS), both of which were completed in 1996, has been a highly visible program involving Congress, federal agencies, environmental groups, academia, and the general public. Although Congress provided the Navy with some relief from the stringent Annex V restrictions in response to the Navy report and EIS, Congress recently expressed in law that ". . . it should be an objective of the Navy to achieve full compliance with Annex V to the Convention [MARPOL 73/78] as part of the Navy's development of ships that are environmentally sound." Accordingly, NavSea is planning to investigate technology and other options for eventual no-discharge ship operations in MARPOL "special areas."

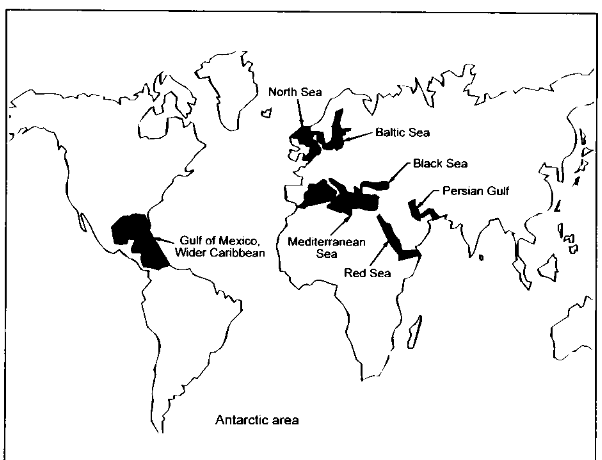

FIGURE 2. Internationally Designated (MARPOL 73/78) "Special Areas" With Special Ship Discharge Restrictions

Current Systems and Practices

Traditionally, trash has been thrown overboard at sea because of the lack of shipboard storage space and to avoid odor, sanitation, fire, and habitability problems. However, the ability and willingness to discharge solid wastes at sea have been curtailed by expanded and new environmental laws and regulations, and by Navy concern about the possible environmental effects of certain ship discharges. After a series of studies and shipboard demonstrations, the Navy imposed upon itself in March 1989 the "3/20 Rule," whereby ships must retain food-contaminated plastic waste during the last three days at sea and retain all other plastic waste during the last twenty days at sea for return to port for proper disposal. The 3/20 Rule immediately reduced the Navy's overboard plastic waste discharge by about seventy percent. The 3/20 Rule forced ships to separate their trash into three categories: food-contaminated plastic, non-food-contaminated plastic, and non-plastic waste. This ushered in new awareness and training requirements for sailors, who then had to learn to recognize plastic from non-plastic items and materials and had to start using segregated trash containers. Congress endorsed this strategy in 1993 when it was made law.

Over the years, individual Navy ships have tried to reduce the volume of solid waste using various commercial trash compactors. Ships also use under-sink food waste grinders for disposal of small food scraps, but these are impractical for the processing of bulk waste food (e.g., a box of spoiled lettuce). Approximately 60 large ships also have simple, batch-fed incinerators. These incinerators were designed decades ago and have no combustion or air-emissions controls. They were intended primarily for classified-document destruction and are not suitable for processing the full range or volume of solid wastes generated on Navy ships.

Navy ships do not have appropriate spaces for efficiently and safely holding trash for return to port. Current shipboard solid waste holding practices can lead to unacceptable quality-of-life degradation and damage control compromises (see Figure 3). In order to gather additional information on the feasibility and ship impacts of trash storage at sea, five ships of the USS *George Washington* (CVN 73) Battle Group were directed to retain non-food solid waste as long as possible while transiting the Atlantic Ocean in early 1996. It was found by independent observers during this sea trial that existing ships can hold trash for only a few days before adverse effects on operations, quality-of-life, and safety become unacceptable. At-sea transfer of trash from combatants to support ships and the additional quantities of waste to be handled ashore were also found to be significant problems. NavSea concluded from these studies and shipboard experiences that if the fleet were to routinely hold and retrograde solid wastes only in MARPOL "special areas," segregated and properly-located trash-holding spaces equipped with sanitation, ventilation, and firefighting services would have to

FIGURE 3. Adverse Impacts of Shipboard Trash Storage on Damage Control and Quality of Life

be installed on combatants and Combat Logistics Force (CLF) ships. For example, 96,000 cubic feet of storage space would have to be reserved on an aircraft carrier to hold 30-days' trash, displacing over 70 crew berths and some aviation storerooms. Without dedicated trash-holding spaces, there would be unacceptable adverse impacts on ship operations; damage control responses to fires, flooding, and chemical attacks; sailors' quality of life (due to sanitation, odor, habitability, and morale problems); and shoreside support activities (due to increased trash offloading and disposal). In addition, establishing dedicated waste storage spaces would be costly, e.g., over $18 million for one aircraft carrier.

RDT&E Strategy

There are three main approaches to shipboard solid waste management:

- Overboard discharge (which is increasingly prohibited or discouraged).
- Mechanical volume reduction and/or other processing to increase waste density and thus the length of time a ship can operate while holding the waste.
- Destruction of the waste so that there is virtually nothing to store and offload.

In response to legislative measures and Navy concern for the marine environment, NavSea formulated a RDT&E program plan in 1993 to develop shipboard solid waste processing equipment that would allow surface ships to discharge only non-plastic, non-floating solid waste (a combination of the first two waste management strategies). This plan recognized that it is unreasonable to expect Navy ships to routinely hold all solid wastes, especially food-contaminated waste, while operating in MARPOL "special areas." Congress accepted this reality of naval operations when it recently revised the no-discharge bans to allow the discharge of non-plastic, non-floating solid waste in these areas. While the Navy sought this legislative change only for operations in MARPOL "special areas," it committed to processing all trash everywhere at sea prior to discharge, thereby eliminating Navy floating marine debris worldwide.

As part of this plan, NavSea developed four solid waste processing machines to enable ships to operate in an environmentally acceptable manner: Large Pulper, Small Pulper, Metal/Glass Shredder, and Plastics Processor. The design of these machines had to meet strict Navy shipboard requirements for performance, reliability, maintainability, vibration, electromagnetic compatibility, noise, operating simplicity, ship systems interfaces, safety, and logistics support. Each of the four systems was successfully evaluated aboard ship and subsequently approved for production and fleet introduction. Prototypes have been operated on a variety of ships, ranging from a frigate to an aircraft carrier, in order to demonstrate their suitability for different ship types, missions, and crew sizes. The Navy is also planning to initiate RDT&E on an advanced thermal destruction system based on plasma-arc technology. Each of these technologies is described below.

Pulpers. The pulpers were designed to grind paper, cardboard, and food waste into a quickly-dispersing, biodegradable seawater slurry (approximately 1% solids by weight) for discharge overboard. The pulpers are essentially much larger, more rugged, and militarized versions of the kitchen-sink food grinders found in many homes and on Navy ships. Both pulpers can be used for classified-document destruction because the slurry is passed through a screen with 12-mm diameter holes. All unpulpable items (e.g., cutlery) are retained in the machine for periodic manual removal. The Large Pulper (see Figure 4) processes 500-1,000 pounds/hour, depending on the waste mix. The Small Pulper is a geometrically similar version of the Large Pulper that is intended for ships without the space for a Large Pulper and that do not generate sufficient waste to require the larger machine. The Small Pulper processes 100-200 pounds/hour, depending on the waste mix. The Large Pulper can handle relatively large pulpable items (e.g., a box of vegetables or telephone books) compared with the Small Pulper (for which cardboard has to be ripped up, for example).

Shredder. The Metal/Glass Shredder (see Figure 5) crushes and tears metal and glass into non-floating pieces which are collected and discharged overboard in a burlap bag that quickly sinks. The Metal/Glass Shredder is a more rugged and militarized version of similar machines widely used in industry. Extremely hard counter-rotating blades break, flatten, and rip waste, which falls into a biodegradable bag. The shredder will primarily process empty food containers, such as metal cans and glass bottles. It is not intended to process pressurized or hazardous material containers (which are handled onboard as hazardous material), but has been designed to protect the operator in the event of trash sorting errors.

Plastics Processor. The Plastics Processor system (see Figure 6) shreds, heats, and compresses waste plastic into easily-handled, stackable disks (at a nominal 30:1 volume reduction). The Plastics Processor consists of a shredder (identical to the Metal/Glass Shredder), one to three Compress-Melt Units (CMUs), one Closed-Loop Cooling Unit (CLCU) for every two CMUs, and a Heat Sealer with special odor-barrier bags (OBBs). The shredder is used when necessary to break down rigid plastic containers and items and to preprocess other waste plastic prior to the CMU cycle. The CMU contains a large heated ram in a heated chamber which squeezes the plastic into disks about one inch thick and 21 inches in diameter. The separate CLCU is used to speed the CMU cool-down to

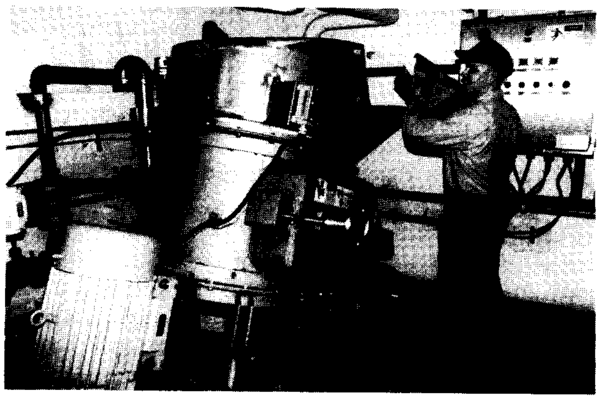

FIGURE 4. Navy-Developed Large Pulper for Producing Dischargeable Slurry of Paper, Cardboard, and Food

FIGURE 5. Navy-Developed Metal/Glass Shredder for Producing Sinkable Bags of Metal and Glass Wastes

achieve the necessary shipboard processing rate. Occasional composite items containing both plastic and non-plastic materials (e.g., insulated electrical wire) and non-plastic items (e.g., cutlery, nuts and bolts) can be safely processed in the machine. The disks will normally be sealed in OBBs to prevent odor problems that might develop from waste food residues during extended storage. The disks will be returned to port for disposal or, if appropriate technology and applications can be identified, for recycling.

Plasma-Arc Thermal Destruction. In its recent report on Navy compliance with MARPOL Annex V, a committee of the Naval Studies Board (NSB) of the National Research Council recommended that the Navy gain experience with modern incinerators. The NSB also recommended that the Navy continue research into advanced waste destruction technologies for possible future shipboard implementation, although no specific technology was singled out. The Navy recognizes that some sort of thermal destruction would be the only technology that might be feasible on Navy ships for the no-discharge management of all solid wastes at sea. Based on a series of studies of the ship impacts of installing and operating conventional marine incinerators on Navy ships, however, NavSea concluded that state-of-the-art incineration systems similar to

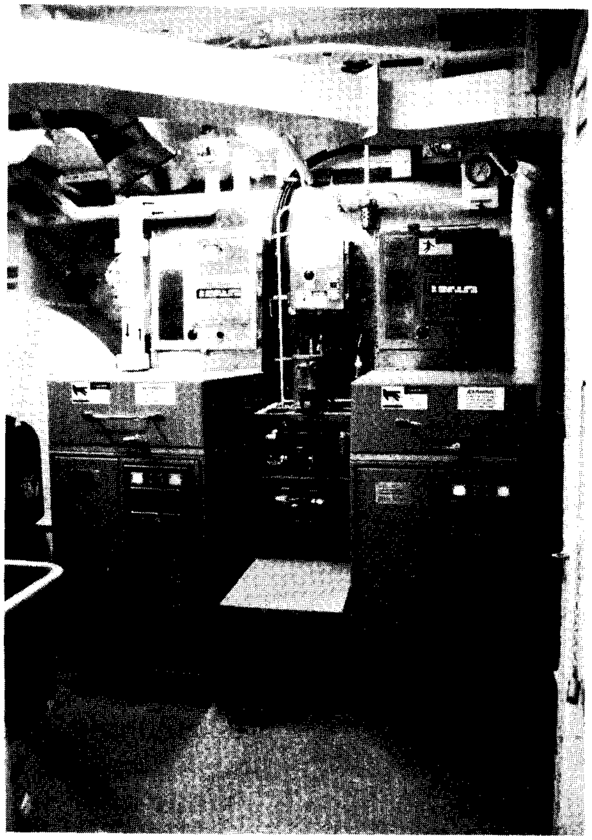

FIGURE 6. Navy-Developed Plastics Processor Heats and Compresses Plastics Waste into Stackable Disks for Return to Shore

those used on many passenger cruise liners are too large and heavy for Navy ships.

The Navy is investigating an advanced thermal destruction technology based on plasma arc pyrolysis. This is a destruction process that operates at high temperatures and vaporizes organic waste to hydrogen and carbon dioxide, and produces a benign, vitrified, inorganic slag. The hydrogen is combusted in a secondary chamber. The high destruction efficiencies, high volume-reduction ratios (75:1), and clean operation offered by this technology would be suitable for Navy ships if the size, weight, and engineering challenges can be solved. The Navy's exploratory development RDT&E program will be evaluating this technology for the destruction of shipboard mixed solid wastes in a land-based facility.

Fleet Implementation

In the process of developing shipboard solid waste processing equipment and preparing its 1996 report to Congress, The Navy:

- surveyed industry for commercially available solid waste processing equipment that may be suitable for use on Navy ships,
- assessed selected processing technologies for shipboard application, identifying the ship impacts and costs of installing and operating the systems,
- studied the potential environmental effects of the discharges from the Navy-developed pulpers and shredder,
- tasked two major independent assessments of solid waste disposal technologies for possible use on Navy ships, and
- prepared an environmental impact statement (EIS) covering all major technological and procedural options for Navy compliance with MARPOL Annex V restrictions in the "special areas."

As a result of these analyses, the Navy concluded that its new suite of solid waste processing systems is the only practical, affordable, and mission-compatible solution for trash management aboard surface ships. The discharge of wastes processed through the Navy pulpers and shredders would have no significant adverse impacts on the marine environment. The Navy's findings have been confirmed by enthusiastic fleet response to shipboard tests of prototype units, interest from foreign navies, and most significantly, congressional and administration endorsement in the form of revisions to legal discharge requirements applicable to the Navy.

The shipboard use of the Navy-designed Large Pulper, Small Pulper, Metal/Glass Shredder, and Plastics Processor will

- avoid or substantially reduce the buildup of trash in ship spaces and the associated sanitation, odor, and morale problems,
- eliminate floating trash from Navy ships worldwide, thereby reducing the environmental and esthetic impacts (e.g., floating trash and beach litter) of current solid waste management practices,
- ease the trash management burden on ships' crews,
- enhance ship operations (e.g., processed non-plastic waste can be processed and discharged during flight operations), and
- comply with legal solid waste discharge restrictions in MARPOL "special areas" and elsewhere.

Two plastics processor production contracts were awarded in July 1995. The first production unit was installed in April 1996 and the fleet backfit program (approximately 200 ships) will be completed by the end of 1998. As of January 1997, over 70 ships had received plastics processors or were having them installed. A similar program for the procurement and installation of pulpers and shredders on existing ships is planned and budgeted. Fleet installations are planned to occur in the FY 98-FY 01 time frame. Should a shipboard plasma-arc system be successfully developed and proven to be effective and practicable, it could be installed on future large ships, such as aircraft carriers and CLF ships.

OZONE DEPLETING SUBSTANCES

The Navy uses various substances for refrigerants, solvents, and firefighting agents onboard ship that destroy stratospheric ozone. Alternatives must be found for these ozone-depleting substances (ODSs) in response to federal bans on their commercial production.

Sources and Characteristics

The Navy relies on two ODSs for its shipboard air-conditioning and refrigeration (AC&R) plants

- CFC-12 in all of the refrigeration plants and in chilled-water air-conditioning plants with cooling capacities up to 125 tons.
- CFC-114 in its chilled-water air-conditioning plants with cooling capacities greater than 125 tons (the Navy is the primary user of CFC-114 as a refrigerant in the U.S.).

CFC-113 and methylchloroform have been used for a variety of cleaning applications (e.g., electronics and O_2/N_2 systems). The use of these ODS solvents is specified or allowed in thousands of military specifications (Mil-Specs) and industrial processes. Halon 1301 is used as the primary firefighting agent in every machinery space on non-nuclear ships.

These CFCs and Halons are ideally suited for their shipboard applications. There are no drop-in replacements for any of the CFC refrigerants or for Halon 1301 that meet Navy shipboard requirements.

Environmental Requirements

International treaties and federal legislation banned the commercial production of

- Halons 1301 and 1211 (as of 31 December 1993), which the Navy uses as firefighting agents,
- Chlorofluorocarbons (CFCs) CFC-11, CFC-12, and CFC-114 (as of 31 December 1995), which the Navy uses as refrigerants, and
- CFC-113, methylchloroform, and carbon tetrachloride (as of 31 December 1995), which the Navy uses as solvents and cleaners.

These substances can continue to be used, but there are several significant problems with continued use.

- There are strict rules on atmospheric releases and recovery.
- Supplies are dwindling and will eventually disappear.
- The prices for these products have been rising dramatically as a result of scarcity and special taxes.
- The Navy must modify specifications and contracts to substitute non-ODSs for ODSs where economically practical.
- There is the potential for further restrictions on the regulated ODS substances and on current alternatives.

Current Systems and Practices

The current shipboard systems using ODSs were described earlier under "Sources and Characteristics."

RDT&E Strategy

The strategy for eliminating the use of ODSs on ships consists of several components

- Establishment of a strategic reserve of mission-critical ODSs.
- Conversion of existing shipboard AC&R plants to use qualified non-ODS refrigerants.
- Design of new non-ODS AC&R systems for future ships.
- Qualification of, and documentation changes for, non-ODS solvents and cleaning agents.
- Identification/design of non-ODS shipboard firefighting systems for forward-fit.

The Navy's progress in these areas is discussed below. (The Navy has received four EPA Stratospheric Ozone Protection Awards in recognition of "exceptional contributions to global environmental protection" arising from these RDT&E efforts.)

Strategic Reserve

The Navy established, through the Defense Logistics Agency, a strategic reserve of selected CFCs and Halons to service ships and submarines until they receive non-ODS cooling and firefighting systems and to service those vessels whose decommissioning will be too soon to justify expensive conversions. In addition, the reserve was intended to support systems for which no suitable or cost-effective substitute was available. When the strategic reserve was established, there were significant uncertainties in projecting future requirements due to assumptions regarding

- fleet demand over the next several decades,
- revised decommissioning schedules,
- long-term shelf-life and leakage rates for ODS stores,
- development and fleet installation schedules for non-ODS systems,
- recovery and recycling rates during maintenance, and
- future priorities for allocation of substances held in the reserve.

The Navy cannot simply rely on these reserves of mission-critical substances to meet continuing fleet requirements, so NavSea has had to move aggressively to develop and implement alternative substances and technologies.

Refrigerants. Substitutes for CFC refrigerants must possess similar thermodynamic properties and cannot compromise AC&R system cooling capacity, power consumption, space envelope, weight limit, acoustic performance, shock resistance, electromagnetic compatibility, reliability, flammability, toxicity, or in the case of submarine applications, atmospheric control and life support requirements. Selection of non-ODS refrigerants requires careful consideration of chemical, physical, environmental, and toxicological properties. Existing AC&R plants require some design and engineering modifications to use even the best alternative refrigerants. These modifications include new lubricants, new thermal expansion valves, compressor speed increases or changeouts, different seals, and new microprocessor-based controls. HFC-134a has emerged as industry's primary non-ODS substitute for CFC-12 refrigerant and, following this practice, NavSea successfully qualified HFC-134a and associated conversion kits for backfitting existing shipboard refrigeration plants. To date, over 320 refrigeration plants on 72 ships have been converted and no longer use CFC-12 refrigerant. For refrigeration systems on future ships, NavSea is developing a new 1.5-ton HFC-134a rotary-vane compressor plant that will be installed on DDG 79 and follow-on ships and on LPD 17. An 800-ton HFC-134a centrifugal compressor air-conditioning plant is being developed for CVN 76. The non-CFC refrigerant HFC-236fa has been selected as the backfit replacement for CFC-114 air-conditioning plants, conversion kits to backfit existing shipboard plants are being developed, and a backfitting program has been budgeted. For air-conditioning systems on future ships, NavSea is developing HFC-134a twin-screw compressor plants for cooling capacities of 125 tons and below (see Figure 7) and a 200-ton HFC-134a centrifugal compressor plant (see Figure 8). The 200-ton air-conditioning plant design will be installed on the DDG 83 and follow-on ships and on the LPD 17.

Solvents. NavSea has identified and, where necessary, qualified alternatives for all of its mission-critical CFC solvent applications. These alternatives include replacement substances (e.g., terpenes, esters, and alkaline detergents) and new or modified processes (e.g., aqueous parts washers). MilSpecs, maintenance cards, and other documentation are being revised to delete ODS solvents. A notable success has been the Navy/industry development of Navy Oxygen Cleaner (NOC), an inexpensive, aqueous, environmentally-benign cleaning agent to replace CFC-113 for the cleaning of critical oxygen systems. NOC is also finding widespread commercial applications in the aerospace, diving, and medical industries. NOC has reduced NavSea's annual consumption of CFC-113 solvent by over 93 percent (1,000,000 pounds) and is now generating royalties and cost savings for the government in excess of $12 million per year.

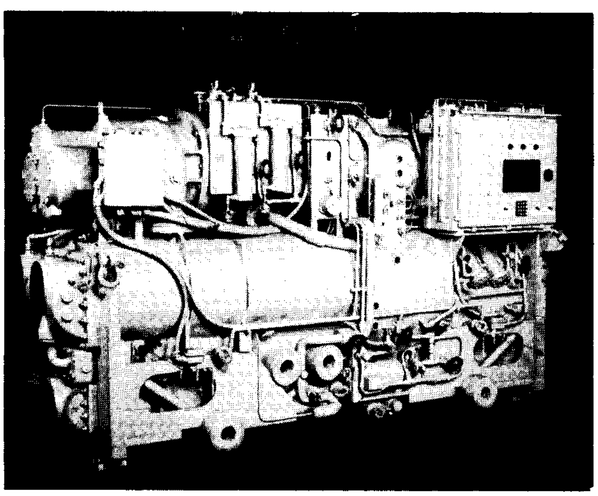

FIGURE 7. 125-Ton HFC-134a (CFC-12 Alternative) Twin-Screw Compressor Air-Conditioning Plant

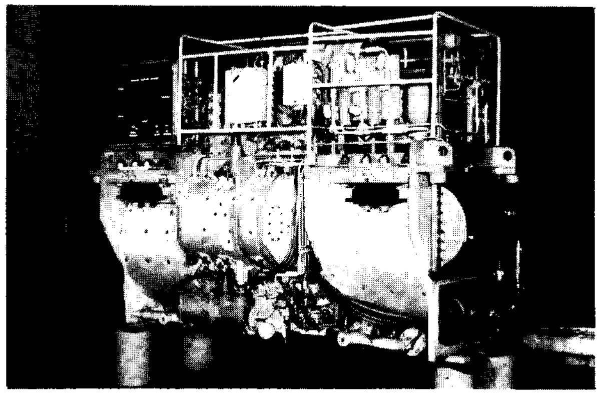

FIGURE 8. 200-Ton HFC-134a (CFC-12 Alternative) Centrifugal Compressor Air-Conditioning Plant

Firefighting Agents. Performance, weight, and space penalties associated with non-Halon fire suppression agents preclude backfits on existing ships. These ships will instead rely on the Navy's strategic reserve of Halon. NavSea has qualified HFC-227ea and fine water mist as substitutes for Halon 1301 for fire protection systems on future ships (including LPD 17 and CVN-76). Work is continuing to refine HFC-227ea system design requirements. Under current plans, LPD 17 will receive fine-water mist fire protection systems in the main and auxiliary machinery rooms and HFC-227ea suppression systems in flammable liquid storage and issue areas and in diesel generator enclosures. NavSea is continuing to investigate other potential replacement agents for Halon 1301 and to optimize recently selected alternatives.

LIQUID WASTES

Sources and Characteristics

A variety of liquid wastes is generated aboard Navy surface ships. The primary liquid effluents are bilge wastes and hotel wastes that result from routine ship operation. Bilge waste is typically a mixture of freshwater and brackish water from distiller dumpings, freshwater and saltwater from cleaning operations, seawater from maintenance operations of seawater systems, and oily residues and drippings from machinery operations and maintenance. Bilgewater generation rates vary with the type, function, and age of the ship, typically ranging from 5,000 gallons/day on a cruiser (CG-47 class) or older destroyer (DD 963 class) to 35,000-50,000 gallons/day on an aircraft carrier (CVN-68 class). Typically, newer ships have significantly lower bilgewater generation rates, e.g., less than 1,000 gallons/day on a new destroyer (DDG 51 class).

Another significant source of oily waste is the compensated fuel ballast systems on DD 963, DDG 993, CG 47, and DDG 51 class ships. Refueling of these ships in port and at sea can produce oil discharges as ballast water is displaced from the fuel tanks.

Hotel wastes are sewage (sometimes referred to as blackwater) and graywater (which is composed of effluents from laundries, galleys, showers, sinks, and deck drains). Ships generate large volumes of hotel wastes, typically 30 gallons/person/day each of sewage and graywater (approximately 24,300 gallons/day on a cruiser and 378,000 gallons/day on an aircraft carrier). Ships equipped with vacuum-operated sewage systems (DD 963, DDG 993, and DDG 51 classes) generate about 10 percent of the sewage volume of other ships.

Navy ships also generate a variety of other liquid wastes in small quantities. These include industrial wastewater (from metal plating, acid cleaning, photo processing, solvent cleaning, painting, etc.), cooling water, steam generator and boiler water blowdown, evaporator brine, weather deck runoff, releases from hull biocide coatings, and releases from hull fittings.

Environmental Requirements

The major restrictions on oily waste (bilgewater, compensated fuel ballast water, and waste oil) discharges from Navy ships are:

- No discharge exceeding 15 ppm oil or causing a surface sheen within 12 nm of land.
- No discharge exceeding 100 ppm oil beyond 12 nm.
- In MARPOL "special areas," no discharge if practicable, otherwise the same as beyond 12 nm.
- Some states have discharge or receiving-water quality standards as low as 0 ppm oil.

The major restrictions on sewage discharges are:

- No discharge of untreated sewage in U.S. territorial waters (within 3 nm).
- In the near future, no discharge within 4 nm and discharge of only comminuted and disinfected sewage from 4-12 nm (if this Annex IV proposal under MARPOL 73/78 is applied to Navy ships by U.S. law).

The major restrictions on graywater discharges are:

- When pierside, pump to shore if equipped to collect graywater in the collection, holding and transfer (CHT) system.
- Some states prohibit or discourage discharges in their waters.
- Possible future international and/or national discharge requirements.

Uniform National Discharge Standards. Several states have been attempting to regulate Navy ship nonsewage liquid discharges under interpretations of their Clean Water Act authority. Examples of state actions directed at or affecting naval vessels include the following:

- Florida cited the USS *Lexington* (AVT 16) for oil/water separator (OWS) effluent exceeding the state's 5-ppm water quality limit.
- Port Everglades in Florida asked the commanding officer of the USS *West Virginia* (SSBN 736) to sign an agreement that his vessel would make no discharges in port.
- Virginia is still attempting to regulate bilgewater and once proposed prohibiting all discharges in port.
- California and New Jersey regulate bilgewater as hazardous waste
- A Canadian ship canceled a planned port visit due to local discharge restrictions.

Congress recognized that inconsistent, uncertain, and sometimes unrealistic state and local restrictions present significant operational and ship design problems for the Navy. A new law was enacted in 1996 to develop Uniform National Discharge Standards (UNDS) for DoD ship liquid wastes. This requires the development and use of marine pollution control devices (MPCDs) where reasonable and practicable for the control of liquid discharges from Navy and other DoD vessels. This determination must take into consideration: the nature of the discharge; the environmental effects of the discharge; the practicality of using the MPCD; the effect of MPCD installation or use on the operation or operational capability of the vessel; applicable U.S. law; applicable international standards; and the economic costs of MPCD installation and use. An MPCD can be shipboard equipment or a management practice. Regulations will be promulgated no later than February 2001 governing the design, construction, installation, and use of MPCDs. The MPCD regulations must be reviewed every five years and revised as necessary to reflect reconsideration of the factors listed above and any significant new information.

Current Systems and Practices

Navy ships today have limited pollution control capabilities that enable them to meet existing requirements for only relatively short periods of time.

Oily Wastes. For bilge wastes, most ships have oily waste holding tanks, gravity parallel-plate OWSs to remove oils and greases, and oil content monitors (OCMs) to prevent oil discharges above legal limits. The OWSs are very effective in removing the bulk (>99%) of the oil from bilge waste and will continue to be installed onboard Navy ships. Nevertheless, they have proven to be incapable on certain ships of reducing the oil content in bilgewater to the 15 ppm requirement because of the use of detergents and other emulsifying agents in machinery spaces and, on newer ships, because of the higher oil concentrations resulting from drier bilges. The Navy's current OCM also experiences performance problems for similar reasons. As a result, some commanding officers are reluctant to use their OWSs in port. Some ports have prohibited the overboard discharge of oily waste completely, requiring instead costly offload and shoreside disposal. On compensated fuel ships, reduced refueling rates and, occasionally, pierside collection of ballast water are the primary methods for minimizing or eliminating inadvertent fuel discharges during refueling.

Non-Oily Wastewater (sewage and graywater). For sewage, Navy ships have CHT systems that allow sewage to be retained for up to 12 hours. This allows ships to traverse no-discharge areas (generally out to 3 nm) and to conduct short-term operations in restricted waters. Once the CHT tanks are full, the ships must either transfer sewage to the pier or discharge directly overboard. Some ships are able to use their CHT systems to hold graywater in addition to sewage where graywater discharge is restricted, but this significantly reduces sewage holding volumes and time. Although CHT systems typically allow current ship movements within the 3-nm no-discharge zone, tank capacities limit the amount of time ships can spend in this area, and more importantly, any extension of the no-discharge zone beyond 3 nm would pose serious operational problems for the Navy. In addition, ships moored in domestic and foreign ports must often bear the high cost of barging or trucking away sewage and graywater. The cost of liquid waste disposal can represent a high percentage of ship operating funds: a preliminary NavSea estimate is in excess of $60 million per year fleet-wide. DD 963 and DDG 993 class ships are equipped with sewage incinerators, but these have experienced significant operational problems over the years.

RDT&E Strategy

The RDT&E strategy for the management of shipboard liquid wastes recognizes that new-construction ships present opportunities to design-in efficient liquid waste management systems to comply with all known regulatory requirements, but that it would not be practical to backfit all existing ships with equivalent capabilities. The Navy's approach is to minimize and, where necessary, to treat liquid wastes to produce water suitable for discharge and a concentrate for storage and/or disposal aboard ship or ashore.

Ultrafiltration membrane systems are the primary technology being developed for the control of bilge waste and non-oily wastewater. This technology was selected after an exhaustive search of liquid waste treatment technologies potentially applicable for Navy shipboard applications. Ultrafiltration membranes (see Figure 9) are semi-permeable, allowing the passage of pure water and dissolved matter while excluding suspended particles above 0.01-0.0001 micron in size. Particle exclusion is based on their physical and chemical interactions with the membrane surface as well as their size. It has been found, for example, that hydrophilic membranes (i.e., those with an affinity for water) perform best with aqueous wastes. One of the primary advantages of membrane filtration, also known as cross-flow filtration, is that the impurities are retained in a concentrate stream, thereby obviating the need for using and replacing filter cartridges. A significant problem that often occurs with membrane systems is membrane fouling, where constituents from the feed stream agglomerate on the surface of the membrane, inhibiting the free flow of

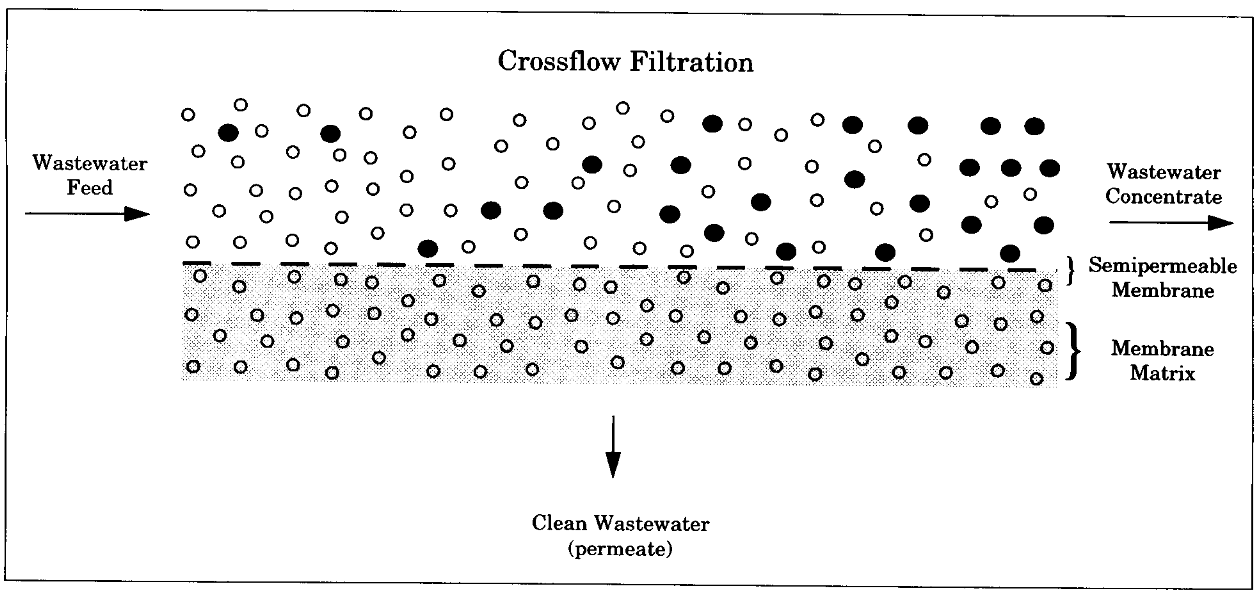

FIGURE 9. Ultrafiltration Process for Wastewater Cleanup

water through the membrane and resulting in reduced throughput. A major objective of NavSea's membrane development programs is to develop engineering solutions to reduce or eliminate membrane fouling. Another objective is to achieve a 100:1 concentration ratio in these membrane systems to maximize the holding time for the concentrate.

Ultimately, some sort of thermal destruction technology will be needed to eliminate the need to hold, discharge, and/or transfer concentrated wastes.

Oily Wastes. Bilge waste cleanup will use an ultrafiltration membrane polishing system downstream of the existing OWS. An extensive membrane screening program led to the selection of ceramic membranes for this application. NavSea has demonstrated oily waste polishing systems in the laboratory and aboard ship. A prototype system operated aboard USS *Carney* (DDG 64) downstream of the ship's existing OWS produced excellent initial results. With over 100 hours of operating experience, the system achieved a concentration ratio of 100:1 and an average effluent oil concentration of 3 ppm from an average influent concentration of nearly 250 ppm. The polisher was operated for 3-5 hours every few days, processing 2,400-3,000 gallons of OWS effluent per cycle. As illustrated in Figure 10, one pump was used in concert with a pressure-regulating valve to maintain an operating pressure of 20-50 psi. The system processed a constant 10 gallon/min feed rate. As the membrane fouled and resistance to water passage increased, the operating pressure was increased to maintain the 10 gallon/min processing rate. A second pump was used to provide a high recirculation rate to create the critical flow shear necessary to minimize fouling. Upon shutdown, the system was flushed with clean water using this high-shear recirculation. The flushing process is considered crucial in maintaining a clean membrane surface. No chemical cleaners were used during shipboard operation of the system.

Figure 11 provides the initial operational data for this prototype membrane system, wherein pressure drop is plotted against operating or processing hours. The pressure drop is measured across the membrane from the feed to the permeate or product side of the membrane (i.e., the operating pressure). This pressure drop reflects the physical state of the membrane and the dynamic fouling that occurs during operation. The pressure drop varied during system operation, primarily as a function of the nature and concentration of the constituents in the feed. Typically, it rose during operation and returned to a lower level after the shutdown flushing cycle. The consistency with which the pressure drop returned to the lower portion of the operating pressure band indicates stable membrane life. Based on these initial results, membrane op-

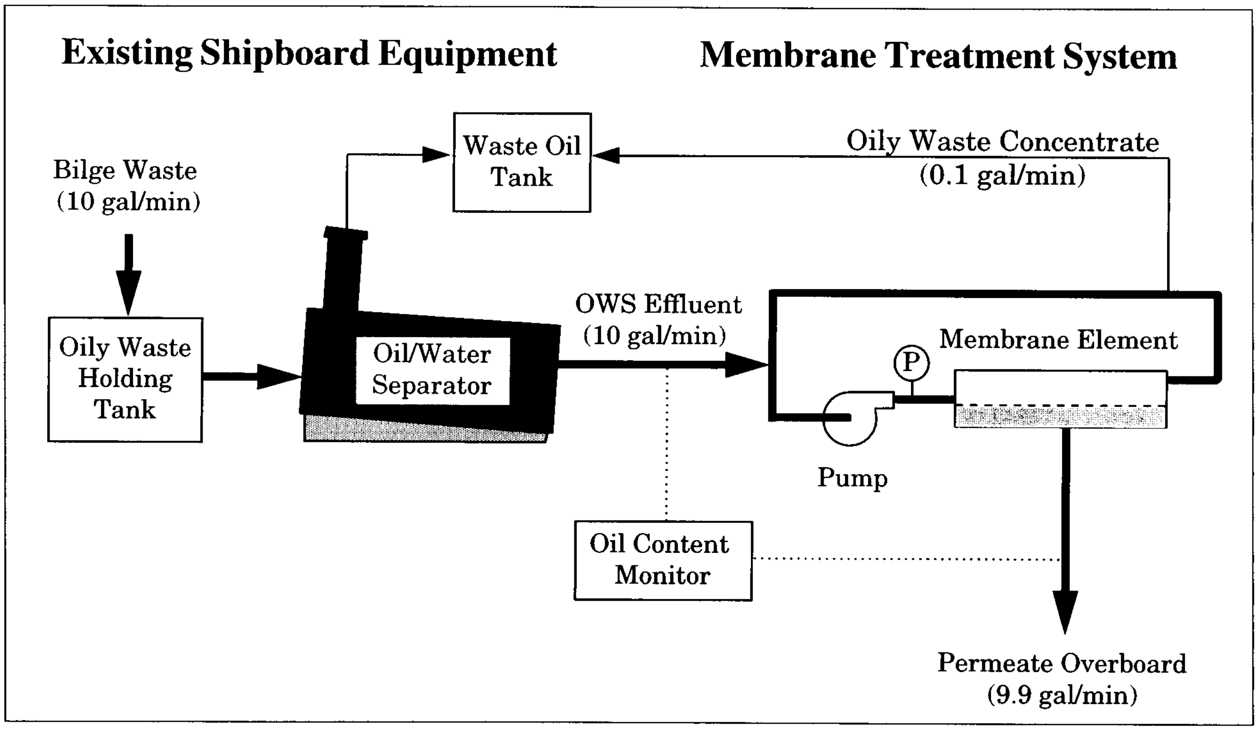

FIGURE 10. Oily-Waste Ultrafiltration Membrane System Diagram

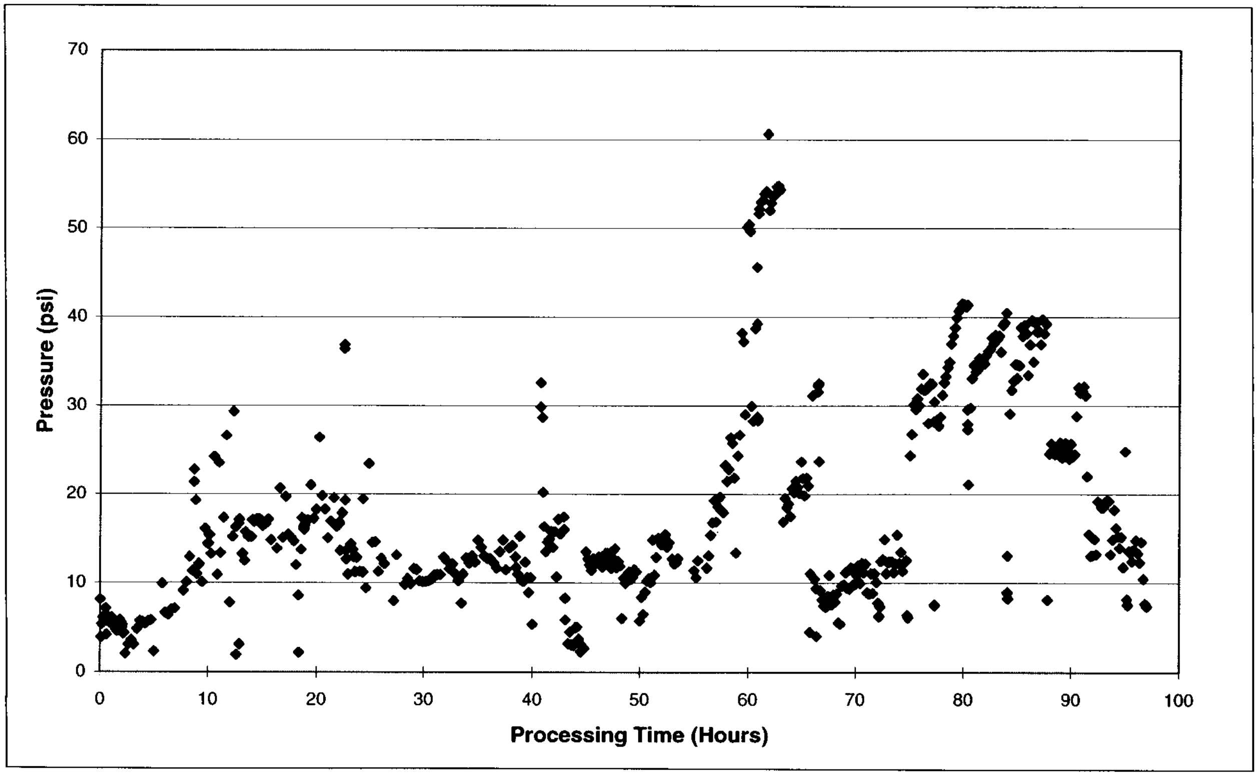

FIGURE 11. Shipboard Oily-Waste Ultrafiltration Polishing System Performance (Trans-Membrane Pressure)

erating life is projected to be over one year. Figure 12 shows samples of membrane system influent (OWS effluent) and membrane system effluent (permeate). Membranes that perform below system requirements would be sent to a shoreside facility for cleaning and refurbishment and subsequent return to the supply system for further service. RDT&E is expected to be completed for this system in FY 99. This prototype system was recently replaced on DDG 64 by an improved engineering development model (EDM) system that is lighter, smaller, and more rugged and that has improved controls (see Figure 13).

NavSea is also developing an OWS effluent polishing system based on materials that adsorb or absorb oil. This is a classic adsorption (or sorption) process wherein the OWS effluent is passed through a packed sorbent media bed, as illustrated in Figure 14. The sorbent material must be carefully selected on the basis of physical and chemical properties to ensure that oil is removed at the desired rate, that the flow characteristics through the system are appropriate, and that media life meets shipboard requirements. The sorbent material must have a high chemical affinity for oil and typically a large surface area (e.g., a cubic centimeter of activated carbon contains over one acre of surface area). The design of the sorbent container and the media packing process itself will also influence the performance of the polishing system. With an effective sorbent and proper system design, there is the potential for oil-free effluent. Preliminary ship tests with a prototype sorbent-media system aboard USS *Arleigh Burke* (DDG 51) (see Figure 15) have achieved effluent oil concentrations of approximately 6 ppm. Extensive laboratory

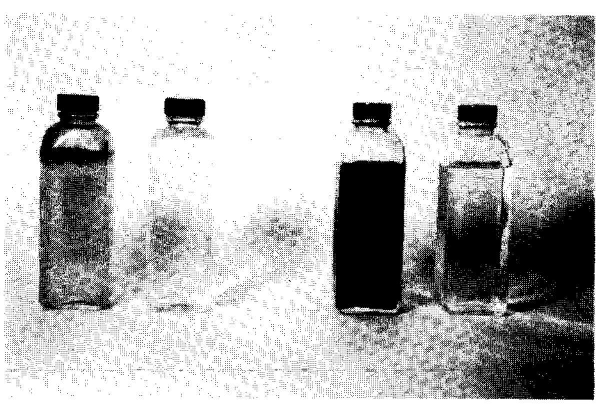

FIGURE 12. Oily-Waste Ultrafiltration Membrane Polishing System Samples: Oil/Water Separator Influent and Effluent (Left) and Membrane Concentrate and Permeate (Right)

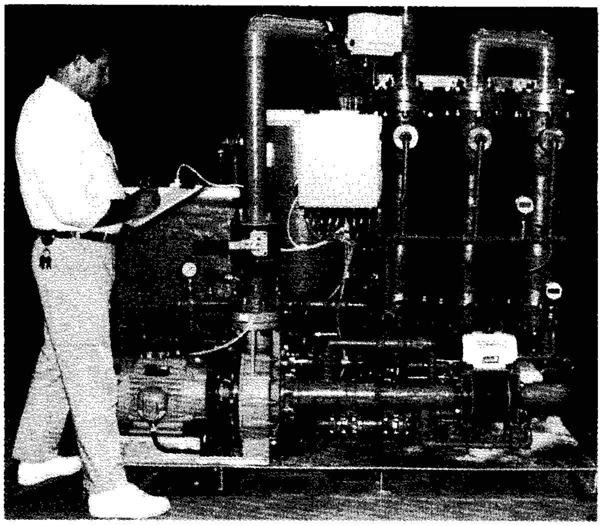

FIGURE 13. Oily-Waste Ultrafiltration Membrane Polishing System (Downstream of Oil/Water Separator)

screening tests are underway to identify the best sorbent media for this application.

Work is also underway to develop a more sensitive and more reliable OCM to support new polishing systems. This OCM will be able to accurately and consistently measure oil concentrations as low as 5 ppm.

For compensated fuel ballast systems, NavSea is investigating ship modifications and procedures to achieve better fuel-water separation and thereby prevent oil discharges exceeding 15 ppm. It is envisioned that various hardware and/or procedural fixes will be implemented on existing compensated fuel ships to minimize oil discharges and permit refueling at design rates. Guidelines will be developed for the optimized design and operation of compensated fuel systems on future ships.

Sewage and Graywater. Non-oily wastewater cleanup will use ultrafiltration membrane treatment. An

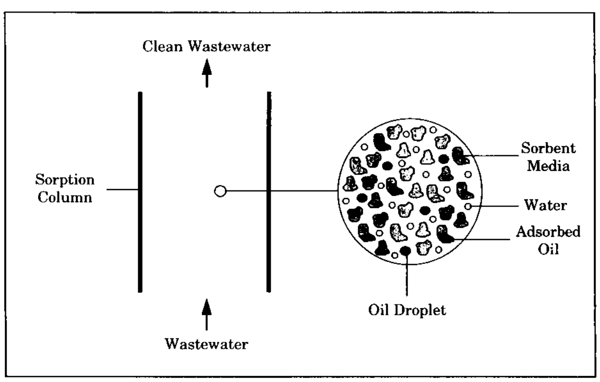

FIGURE 14. Oily-Waste Sorbent Polishing Process

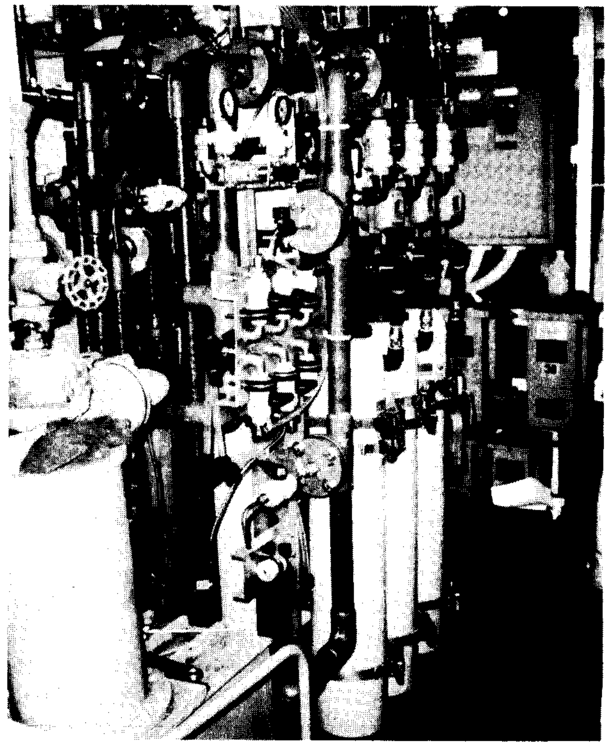

FIGURE 15. Oily-Waste Sorbent Polishing System (Downstream of Oil/Water Separator)

extensive membrane screening program led to the selection of polymeric membranes for graywater and sewage applications. Graywater/sewage membrane systems have been tested in the laboratory and pierside at Norfolk Naval Base with graywater and with mixed graywater/sewage from naval combatants. Results to date have demonstrated over 600 hours of stable performance (i.e., little or no membrane performance decline) with graywater feed, but inadequate performance with combined sewage/graywater feed. Reduction of suspended solids in the membrane effluent was in excess of 99 percent, meeting program objectives. While high levels of rejection of biological oxygen demand (BOD) and fecal coliform are achieved by membrane ultrafiltration (60 percent and 99.99 percent, respectively), it has been determined that pre-treatment and post-treatment methods will be required to control BOD and fecal coliform to acceptable levels. For example, the application of aerobic conditioning of membrane sewage and graywater feeds in recent laboratory and pierside studies demonstrated excellent reduction in BOD (below 50 ppm). Similarly, evaluations of ultraviolet post-treatment disinfection have indicated effective fecal coliform reductions below 200 colonies per 100 ml. A full-scale prototype membrane system incorporating aerobic conditioning will be tested with ship-generated sewage and graywater on a pier at a Navy base in FY 98. This effort will be followed by a shipboard installation and evaluation. This graywater/sewage ultrafiltration RDT&E is expected to be completed in FY 02.

Thermal Destruction. NavSea has developed an integrated liquid waste treatment concept that could eliminate non-compliant ship discharges and release ships from costly, inconvenient, and undependable shore support. In this concept (see Figure 16), membrane concentration systems would dewater bilge and hotel wastes (as previously described), the clean effluents would be discharged, and the concentrates would be evaporated/incinerated in a thermal destruction system. Additional polishing stages may be required to remove trace impurities that pass through the membranes. The thermal destruction technology program is a three-phase effort to ultimately develop a multifunctional incinerator to destroy the concentrated liquid wastes and waste oil.

The first phase is troubleshooting the existing vortex-type sewage incinerator on DD 963/DDG 993 class ships (see Figure 17). This will bring the system up to as-designed operating condition and update maintenance and training documentation to ensure that these ships can operate the incinerators as needed and to document lessons learned. The second phase is to determine the feasibility of upgrading the incinerator to also destroy concentrated graywater, concentrated oily waste, and waste oil. This task is being accomplished through the iterative use of a computational fluid dynamics (CFD) model and laboratory testing of an actual physical model to verify the CFD model results. Only through solving the problems associated with the present Navy liquid waste incinerator will enough be learned to develop a reliable multifunctional system. Conceptually, the processing rate of the Navy's existing vortex incinerator would have to be increased by 50 per-

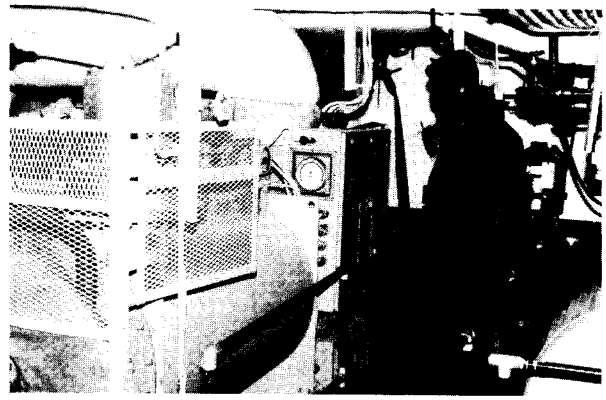

FIGURE 17. Existing Shipboard Vortex Sewage Incinerator

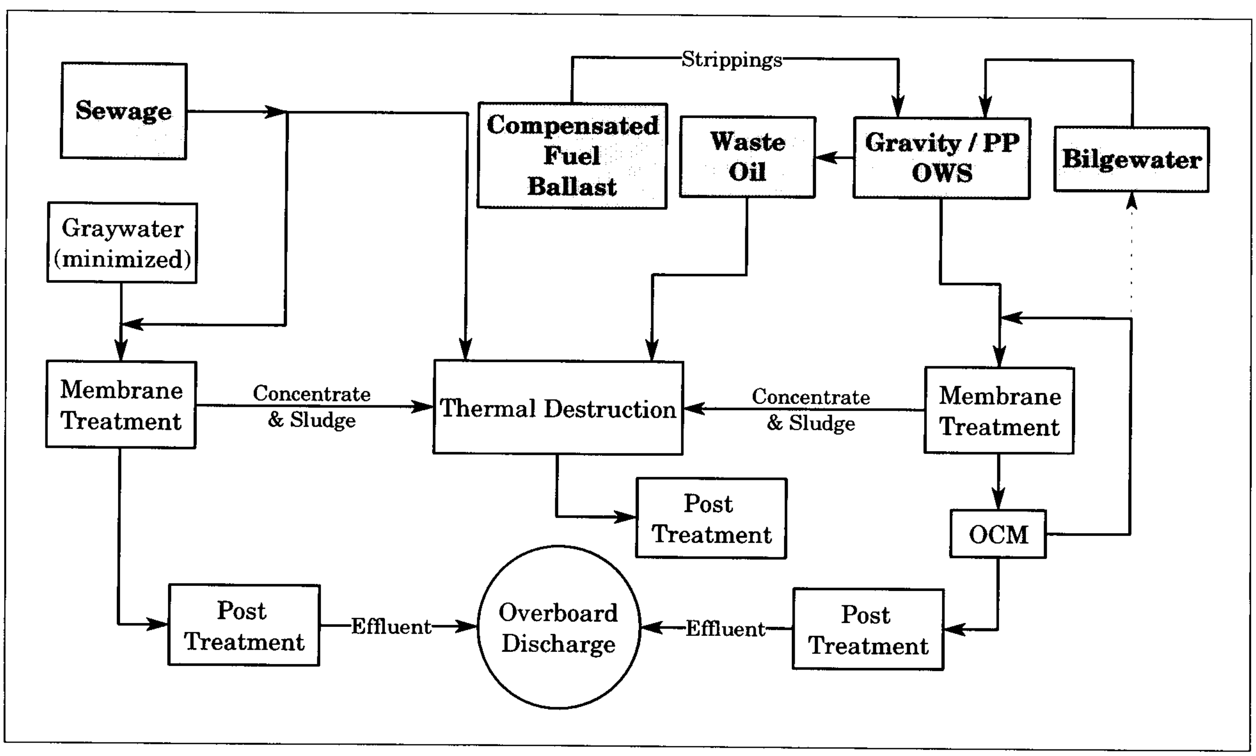

FIGURE 16. Strategy for Integrated Liquid Discharge System (Existing Shipboard Systems Shaded)

cent in order to process vacuum-collected sewage, concentrated graywater, concentrated oily waste, and waste oil. This would, in turn, require increases in weight, footprint, fuel firing rate, air blower capacity, feed pump rate, internal temperature, and flue gas flow rate. The third phase is to develop an appropriately sized, fully multifunctional liquid waste incinerator capable of destroying concentrated liquids on a modern combatant ship. Presently, the sewage incinerators aboard USS *Thorn* (DD 988) have been brought up to fully operational status, the CFD model has been completed, and a combustion testing facility is being set up at the Naval Surface Warfare Center Carderock Division. According to the current RDT&E schedule, a shipboard multifunctional incineration system will be ready for operation by the middle of the next decade.

HAZARDOUS MATERIALS

The Navy must minimize and properly manage the hazardous materials (HMs) used onboard ship for crew health and safety reasons and because used/excess HMs become regulated as hazardous waste once they are transferred ashore. The use, handling, storage, and disposal of shipboard HMs represent significant safety concerns, environmental risks, and monetary costs.

Sources and Characteristics

Thousands of HMs have been used on Navy ships, including solvents/degreasers, cleaning agents, adhesives, sealants, lubricants, hydraulic fluids, rust/corrosion inhibitors, and ethylene glycol. These materials require special handling, storage, and disposal procedures to minimize health and safety risks to sailors and shoreside personnel.

Environmental Requirements

The major legal requirements applicable to Navy shipboard management of hazardous materials are:

- No discharge of harmful quantities into U.S. waters out to 200 nm.
- Regulated as hazardous waste once transferred ashore.
- Pollution-prevention recycle, reuse, and reduce requirements applicable to all federal agencies.

Additional Navy policy includes:

- To the extent practicable, ships shall retain used/excess HM onboard for shore disposal.
- Various occupational safety and health requirements.

Current Systems and Practices

HMs are being used, handled, and stored aboard ship much more carefully and intelligently than in the past for several reasons:

- The Navy continues to seek better ways to minimize the health and safety risks to ships' crews and shoreside personnel.
- Ships' used/excess HMs become regulated as hazardous waste (if not reused) as soon as they are transferred ashore for disposal or other management.
- There are burdensome paperwork and accountability requirements associated with HM procurement and management.
- HMs pose potential environmental hazards if inadvertently released or disposed of improperly.

Over the last 10 years, the Navy has developed and implemented several programmatic and procedural tools to enable the fleet to minimize its reliance on HMs and to efficiently and safely manage those HMs that must continue to be used aboard ship. There are lists of HMs approved for use aboard ship, and many ships have special HM issue and storage spaces to control the use of these materials. Ships also use inventory and tracking systems to manage HMs to provide information needed by shoreside activities to properly dispose of offloaded hazardous wastes. There is also a growing number of pollution prevention (P^2) initiatives aimed at shipboard HM source reduction, recycling, and reuse.

RDT&E Strategy

The Navy's shipboard HM strategy is threefold:

- Identify/develop suitable non-hazardous or less-hazardous substitutes where practical and ensure proper engineering approval and controlling document changes.
- Where HMs cannot be eliminated, develop efficient and safe procedures for identifying, tracking, and transferring HMs that must continue to be used aboard ship.
- Identify and prove P^2 opportunities.

Hazardous Materials Control and Management (HMC&M). Ongoing efforts in this area include:

- Developing the Shipboard Hazardous Material Database, which coordinates/integrates several existing Navy, DLA, and EPA HM-related computerized resources.
- Developing and refining technical criteria for identifying and screening potential HM substitutes.
- Implementing a Navy-wide change from Type II to less-hazardous Type III PD-680 solvent/cleaner (revising nearly 5,000 maintenance cards).
- Identifying and reviewing potential substitutes for adhesives and sealants (930 products and 2,500 maintenance actions).
- Identifying and reviewing potential substitutes for corrosion preventers, lubricants, and functional fluids (thousands of products and tens-of-thousands of maintenance requirements).
- Evaluating the potential use of bio-enzymatic cleaners as an alternative for shipboard chemical/mechanical cleaning techniques.
- Evaluating potential shipboard applications of environmentally acceptable (biodegradable) lubricants.

Pollution Prevention. NavSea's P^2 program seeks to identify and evaluate commercial off-the-shelf products for ships that can achieve significant HM reductions and that can be quickly transitioned into the fleet. At this time, nine ships are serving as test platforms for various products. Among the products being evaluated are an ethylene glycol recycler, hydraulic fluid purifier, paint gun washer, aqueous parts washer, maintenance-free batteries, and primer/topcoat touchup pens. Fleet feedback from early shipboard experience with these types of P^2 solutions has been enthusiastic.

SHIPBOARD PAINTS AND COATINGS

Paints and coatings applied to Navy ships represent the single largest source of air pollution emissions at shipbuilding and ship repair activities. The application and removal of paints and coatings present legal compliance problems, as well as entail significant costs and manpower requirements. Advanced paint system technologies are critical for:

- Complying with current and pending environmental regulations.
- Extending material service life performance beyond current maintenance periods.
- Addressing reduced Navy maintenance budgets.

Sources and Characteristics

Current U.S. Navy paint preservation systems involve the use of coatings with 40 to 65 percent solids content. This results in significantly more atmospheric emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) compared with paints with advanced chemistries (i.e., 95 to 100 percent solids content).

Environmental Requirements

Marine-type non-hull paints and coatings are highly regulated materials. Federal regulations limit HAPs, e.g., through National Emission Standards for Hazardous Air Pollutants (NESHAPs). There are EPA and state regulations restricting HMs (e.g., benzene) that are associated with Navy painting/coating applications. EPA has proposed lowering the national standard for particulate matter emissions from PM-10 to PM-2.5, which would regulate much smaller particles. State and local jurisdictions have stringent regulations that exceed existing materials used by the Navy, e.g., the South Coast Air Quality Management District in Southern California recently enacted a requirement that paints sold in that region must be non-polluting by 2008 and the San Diego Air Pollution Control District has restrictions on general-use marine epoxy paints. California, Connecticut and Pennsylvania have marine coating regulations that restrict VOCs. Federal P^2 goals also affect Navy paint and coating systems and practices. In addition, the Occupational Safety and Health Administration (OSHA) has regulations for heavy metals in industrial paint materials that add a personnel health and safety angle to the environmental concerns.

Current Systems and Practices

The U.S. Navy uses many types of paints and coatings to protect metallic and non-metallic substrates aboard ship. These include epoxies, alkyds, vinyls, and enamels. Paint removal and application periodicities are related to scheduled ship availabilities and the condition of the surfaces to be protected. The Navy complies with all environmental regulations and personnel health and safety standards related to emissions generated during paint removal and application. Paint personnel typically wear personal protective equipment in order to minimize exposure and potential health risks.

RDT&E Strategy

To develop environmentally compliant Navy shipboard paints and coatings that will ensure regulatory compliance, reduce maintenance costs by up to 20 percent, and reduce worker exposures for existing and future ships, NavSea will:

- Identify and evaluate new coating systems to achieve lower VOC and HAP levels.
- Evaluate, demonstrate, and implement innovative, state-of-the-art practices in ship preservation that will reduce the toxic chemicals and pollutants generated or emitted.
- Develop techniques to assess the condition of existing coating systems to determine the need for recoating and optimize recoating schedules to minimize pollution generation resulting from coating repair.
- Identify PM emissions released during surface preparation and paint application and identify potential control technologies.

The primary source of technology for this effort is the paints and coatings industry, including international and domestic manufacturers of coating systems and associated equipment, and industry standards societies. Advanced-technology paints possess added environmental and service-life performance advantages. For example, fewer coats are needed to achieve desired film and some new systems possess edge-retention characteristics in order to safeguard corrosion-prone edges and complex geometries.

Fleet Implementation

Improved and new paint/coating technologies and practices will be qualified and transitioned directly to the fleet through documentation revisions.

ASBESTOS ELIMINATION

NavSea's goal in the asbestos elimination program is to eliminate shipboard personnel exposures to asbestos and to minimize asbestos in ship construction, repair, and maintenance.

Sources and Characteristics

Asbestos was widely used in industry and the Navy due to its heat-, fire-, electrical-, and chemical-resistant properties. The Navy used it extensively in thermal and fire insulation, acoustical insulation, pipe lagging, packing and gasket materials, brake and clutch linings, winch and capstan brakes, and flooring materials. Asbestos has become a recognized health hazard that can cause lung disease, including cancer. Significant legal liability risks are associated with human exposure to asbestos. Asbestos products are essentially no longer manufactured in the U.S. due to these concerns.

Environmental Requirements

The use, removal, disposal, and substitution of asbestos is controlled by environmental and occupational safety and health regulations and policies and by industry practices. The EPA promulgated a rule in 1989 to phase out asbestos, but this rule was struck down in court in 1991, and the EPA has yet to re-establish this program. Nevertheless, most manufacturers in the U.S. have ceased the production of asbestos-containing products due to liability concerns. EPA established a NESHAP for asbestos, which applies to work conducted in Navy shore facilities and aboard ship. The NESHAP encompasses notification, ripout, sampling, handling, transporting, disposal, and other requirements and restrictions. It is official Navy occupational safety and health policy to eliminate human exposure to asbestos by substituting non-asbestos materials. There is also specific Navy guidance for the removal and disposal of asbestos.

Current Systems and Practices

The Navy began in 1971 to reduce or eliminate the use of asbestos thermal insulation on ships to reduce potential human exposure. Beginning in 1974, asbestos-free thermal insulation materials were specified for all uses except pipe hanger liners, but most ships commissioned through 1976 are equipped with some asbestos thermal insulation. In its ongoing program to identify, evaluate, and introduce non-asbestos components into Navy shipbuilding applications, approximately 100 MilSpecs have been revised to eliminate asbestos (e.g., in thermal insulation, paints, adhesives, firefighting clothing and equipment, and various gaskets and seals). Asbestos has been replaced in insulation and lagging materials primarily by man-made vitreous fibers. Asbestos is still used in a few Navy applications for which it is more difficult and costly to find acceptable substitutes.

RDT&E Strategy

Manufacturers of non-asbestos packing, gasket, and friction materials have developed products that are commercially available, but have not been tested for demanding Navy shipboard applications. In general, existing industry standards and test methods are not adequate for qualifying commercial products for Navy use. NavSea must develop its own test methods and test equipment to evaluate non-asbestos materials under simulated performance conditions. The NavSea program must take into account both nuclear and non-nuclear requirements, which include specific chemical screening tests not used in industry.

Current work focuses on gaskets for aqueous film forming foam (AFFF), F76 fuel, phosphate ester hydraulic fluid, hot air, and non-CFC refrigerant applications. The most difficult of the asbestos-containing components to replace are the packings, gaskets, and windlass and crane braking materials because of rigorous requirements. These materials are being currently evaluated, and the major item testing should be completed in FY 99.

Fleet Implementation

Qualified non-asbestos substitutes will be entered into a special database linking the old asbestos product with the non-asbestos product. New or modified performance specifications will be prepared, technical documentation will be revised, and fleet supply support (including Standard Navy Valve Yard) will be provided as needed. Commercial technical associations, such as the Fluid Sealing Association, will be advised of all NavSea-approved items.

Conclusion

It is important that Navy engineers and designers responsible for the design of new surface combatants are aware of existing and anticipated environmental laws and regulations that will affect the operation of the new ship class. They should also be familiar with the environmental technologies being developed to address pollution problems on future ships. Table 2 lists the environmental technologies recently produced by or being pursued by NavSea's Advanced Development RDT&E that present opportunities for future ships. These technologies will:

- Enhance the Navy's operational flexibility by allowing ships to operate in accordance with applicable environmental regulations.
- Maintain or enhance shipboard quality of life.
- Provide additional ports-of-call opportunities.
- Reduce ship dependence on shoreside support services.
- Demonstrate U.S. leadership in marine environmental protection.

Environmental compliance by future ships is a win/win situation: incorporating new and emerging environmental technologies into new designs will allow U.S. Navy ships to be both operationally effective and environmentally sound.

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TABLE 2

Environmental Technology Opportunities for Future Ships

SOLID WASTES

Plastics Processor for reducing volume of all plastics waste for shoreside disposal (currently being installed)

Large Pulper and Small Pulper for grinding paper, cardboard, and food for overboard discharge (installations will begin late-FY98)

Metal/Glass Shredder for tearing/crushing metal and glass for overboard discharge (installations will begin late-FY98)

Plasma-Arc Thermal Destruction for disposal of all solid wastes on large ships (RDT&E to begin FY98)

OZONE-DEPLETING SUBSTANCE ELIMINATION

HFC-134a Rotary-Vane Compressor Refrigeration Plant for forward-fit alternative to CFC-12 (RDT&E underway and first installation planned for DDG-83)

HFC-134a Twin-Screw Compressor Air-Conditioning Plant for forward-fit cooling capacities up to 125 tons (RDT&E underway)

HFC-134a Centrifugal Compressor Air-Conditioning Plant for forward-fit cooling capacities above 150 tons (RDT&E underway)

HFC-227ea Firefighting Agent for forward-fit (qualified for certain shipboard applications)

Fine Water Mist fire suppression systems for forward-fit (qualified for shipboard machinery spaces)

Alternatives for CFC-113 and Methylchloroform Solvents/Cleaners for numerous shipboard and shoreside applications

LIQUID WASTES

Oily Waste Membrane Ultrafiltration Polishing System for forward-fit and backfit on larger ships (RDT&E underway)

Oily Waste Sorbent Polishing System for backfit on smaller ships (RDT&E underway)

Compensated Fuel Ballast System modifications for existing ships and design guidance for new ships (RDT&E underway)

Advanced Oil Content Monitor for forward-fit with new OWS effluent polishing systems (RDT&E underway)

Graywater/Sewage Membrane Ultrafiltration Treatment System for forward-fit (RDT&E underway)

Multifunctional Incinerator for forward-fit as part of Integrated Liquid Discharge System concept for destroying concentrated liquid wastes and waste oil (RDT&E underway)

HAZARDOUS MATERIALS

PD-680 Type III. Less-hazardous substitute for PD-680 Type II (Navy-wide change being implemented)

Substitutes for Adhesives, Sealants, Corrosion Preventers, Lubricants, and Functional Fluids. Testing and qualification underway

Pollution Prevention Equipment. Variety of commercial products being evaluated for backfit and forward-fit

SHIPBOARD PAINTS AND COATINGS

Environmentally Compliant Materials and Processes. RDT&E underway to develop low-VOC/low-HAP coatings

ASBESTOS ELIMINATION

Identified non-asbestos substitutes for thermal insulation, paints and adhesives, fireman's clothing, and gaskets for water and steam service; evaluating potential substitutes for gaskets for AFFF, F76 fuel, phosphate ester hydraulic fluid, hot air, and non-CFC refrigerant applications

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COMMENTS BY

Larry Koss

The authors should be commended for their excellent work in describing 1) the need for warships to be perceived as "environmentally sound," and 2) the specific technologies and capabilities to achieve the vision of the Environmentally Sound Ship of the 21st Century (ESS 21), a vision endorsed not only by the U.S. Navy, but by the NATO navies as well.

The need for environmentally sound ships was also articulated and confirmed during my recent discussions with the navies of central and eastern Europe and the Asia-Pacific area. The real challenge today, as in the last 25 years, is the advancement and packaging of the technology to meet shipboard requirements.

The authors should also be congratulated for their ability to develop, test, evaluate and transition to procurement shipboard systems to comply with today's complex environmental requirements while planning for an uncertain future. Perhaps the most challenging aspect of this difficult task is understanding the operational fleet's need to address domestic and international marine environmental requirements while operating in a political environment that may range from littoral station-keeping to full combat operations.

To be operationally capable, a warship must remain free to operate anytime and anywhere unconstrained by environmental regulations.

Frequently, people, unfamiliar with warships and the myriad missions they face, espouse a simplistic view and misconstrue the ESS 21 concept. They imply that concern for the marine environment and compliance with environmental regulations will be the sole driving requirement.

The authors here, however, have correctly articulated ESS 21's underlying tenet: to be operationally capable, a warship must remain free to operate anytime and anywhere unconstrained by environmental regulations. Additionally, the authors have stated that operating and maintaining environmentally sound ships must be cost-effective. In other words, future ships must not only be "environmentally sound," they must also be "smart ships."

The authors have discussed specific technologies under development as well as equipment and systems being produced and installed aboard existing ships. These equipment developments were driven by national legislation requiring Navy compliance. However, these new systems will not only protect the environment, but will also significantly ease the waste processing manpower burden, enhance the public image of our fleet both at home and abroad, drastically reduce (if not avoid) the cost of compliance driven alternatives like waste retention and retrograde, as well as improve the quality of life for our sailors.

The authors emphasize that "new environmental technologies must be developed and incorporated early in the design of new vessels." This key thought must be institutionalized and acted upon throughout the ship design and systems development community. Our experience has been that the cost of installing new equipment aboard existing ships can often be seven times the cost of procuring the same equipment. It is far more affordable to build environmental capability into future ship designs than to retrofit that capability at a later date.

Recent revisions to defense acquisition regulations require acquisition program managers to more fully incorporate environmental considerations, particularly pollution prevention, into the design of new weapons systems. Our next challenge is to recognize how an increased emphasis on pollution prevention in acquisition may affect technological opportunities for future ship designs.

I challenge the authors and the naval shipbuilding community at large to go beyond the task of developing and installing waste processing systems. They should "think outside the box" and apply the same level of thought and talent toward minimizing waste generation wherever possible. Taken one step further, ship and equipment designers should consider (in a macro sense) not only waste minimization but solutions that avoid waste generation all together, such as new configurations, alternative materials and improved procedures. Will this solve all shipboard waste problems? Of course not; but it should help us to focus upon future technological requirements.

What new technologies or design principles can be employed on future ships? Are they affordable? Can we afford not to employ them? What waste streams can we reduce or eliminate? Can we identify reliable environmental life cycle cost techniques, mandate their use early in the ship and system design process, and thereby drive trade-offs in acquisition to more intelligently control operation and maintenance costs over the next 20 years? Are there other opportunities we are missing in our new ship designs that can allow us to realize our vision of environmentally sound ships of the 21st Century?

Our work is progressing well to retrofit new technologies into existing ships basing many decisions on "affordability." However, for new ship designs, we must put ourselves in the year 2005 and beyond where we may not have the luxury of compliance only to the extent that current development and procurement philosophies deem "affordable." Will we and our ships be ready to meet that challenge?

AUTHOR'S RESPONSE

I appreciate Mr. Koss' supportive remarks and welcome his challenge to the ship R&D, design, and engineering communities to think and work smarter as we strive to make the environmentally sound ship of the 21st century a reality. Mr. Koss has been a key player in promoting the fundamental culture change needed within the Navy to achieve this vision. For this reason, I am sure he would agree that integrating environmental considerations into ship design, construction, and operation faces several significant challenges:

- Balancing the warfighting and other national defense requirements for our ships against the space, weight, and services needed by environmental systems.
- Implementing a "paradigm shift" in an organization as large, diverse, and geographically dispersed as the Navy.
- Working within programmatic and monetary constraints imposed by the shrinking defense budget and downsizing pressures.

The good news is that we can see evidence of this new culture taking hold today as we look around the Navy. For example, DoD acquisition policies have made environmental documentation an integral part of major acquisition programs.

As Mr. Koss suggests, the ideal solution for Navy ships would be to completely avoid generating wastes. If we did not generate shipboard wastes in the first place, we could avoid several things:

- The need for shoreside infrastructure to offload and dispose of ship wastes.
- The need to develop, test, procure, install, and logistically support shipboard pollution abatement systems.
- The need to predict, when we are designing a new platform, what environmental laws and regulations the Navy may face five, fifteen, or thirty years from now.

A non-polluting ship would also enhance the Navy's public image and further demonstrate the Navy's commitment to its environmental stewardship responsibilities. We agree, however, that the myriad military, industrial, and human activities aboard a Navy ship cannot be curtailed in such a way as to eliminate the need for some "end-of-the-pipe" controls. Furthermore, the culture change necessary for minimizing or preventing shipboard wastes must encompass the entire breadth and depth of the Department of Navy as well as associated organizations, including laboratories, fleet, public and private shipyards, contractors, sailors, training curricula, resource sponsors, and the various R&D and life-cycle offices within the Systems Commands. The organizational and institutional complexities involved in bringing all of these components of the Navy into the environmental fold are very real.

Mr. Koss characterized current shipboard waste management solutions as the product of a Navy culture focused upon affordability. The concept of affordability, however, must not be limited to the up-front costs of developing and installing shipboard pollution control systems. My office is trying to determine the life-cycle costs of Fleet environmental compliance and the payoffs of alternative solutions in order to quantify the Navy's return on its investment. The payoffs are not limited to protection or enhancement of the marine environment. There are also significant cost reductions for the Navy itself, for example, by reducing ship dependence on shoreside waste disposal support where appropriate. There are also mission, readiness, quality-of-life, and other benefits that are difficult to factor into cost equations. The bottom line is that shipboard environmental RDT&E expenditures must be regarded as an investment in the Navy's future operational capabilities.

As Mr. Koss can confirm, the U.S. Navy is the world leader in maritime environmental protection. NavSea has developed and continues to develop ship systems and practices that respond to existing and emerging environmental laws and regulations and that maximize the environmental compatibility of naval operations in the world's oceans and littoral areas. Nevertheless, we must, and can, rise to Mr. Koss' challenge for the future. The Shipboard Waste Management program accepts the challenge, but we cannot do it alone. We must enlist the cooperation and expertise of the design, sponsor, and acquisition communities in order to ensure that the Navy adequately and cost-effectively protects the environment without compromising military mission.